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Analysis of electrical power form the wind farm sitting on the Nile River of Aswan, Egypt

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ABSTRACT

Establishment of the wind farms is very large and widely distributed throughout the world as well as in Egypt. Aswan City along the Nile River possesses a huge potential of wind energy. For this purpose, hourly wind data, which were observed between the years 1995 and 2004 at Aswan meteorological station were used. A statistical analysis was carried out from which the annual wind speed was found to be generally high 6.9–7.5 m/s during the medium hub heights 50–70 m and most of the time (79%) the wind speed is in the range 5.3–6.1 m/s over the year at 10 m height. The wind speed distribution were represented by the Weibull distribution. Where the wind speed is sufficient during the whole year for high power generation.

New technical analysis for the monthly wind energy available and the monthly energy pattern factor (E.P.F.) for the station was made. Moreover, calculations show that the annual mean energy density available was 200 kWh/m^2 at 70 m height in Aswan region, that is very high potential and suitable for large electricity generation.

Furthermore, the monthly plant load factor (PLF) has been determined. Locally and technologically suitable wind turbine for this station must have rated power greater than 1 MW at 100 m height above the ground level.

The aim of this research, was to study the possibility of construction a wind farm extending up to a capacity of 45 MW. Where 30 wind turbines model (*Fuhrländer FLMD 77*) with a capacity of 1.5 MW were considered at Aswan station. After usage the well known WASP software, the energy output 152 GWh/year can be generated from 45 MW wind farm in this site. Then additionally, the expected electricity generation cost was 2€ cent/kWh. This specific price is economically valuable according to the national tariff system.

Contents

1. Introduction

Wind energy has a very good prospect to contribute our future energy needs, but in order to realize this potential in full scale, the

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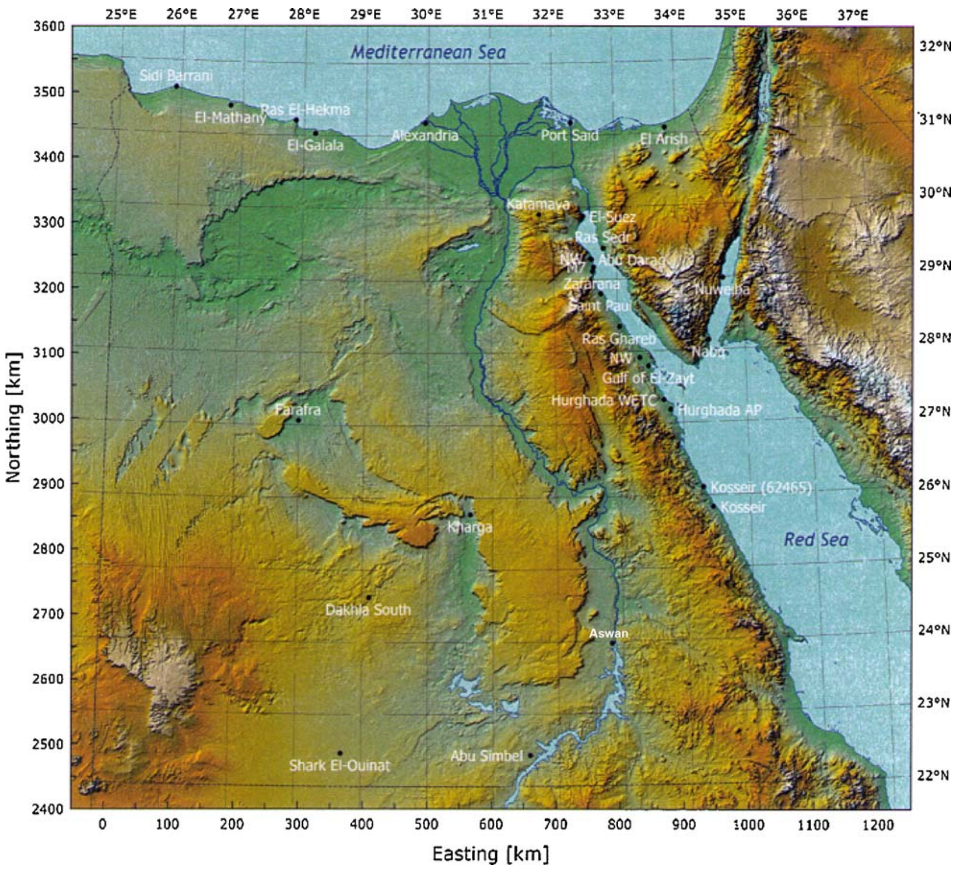

Fig. 1. Shows the location of Aswan Meteorological station along the Nile River in Egypt.

technology must be both, economically competitive and environmentally acceptable [1,2].

The oldest known use to wind energy dates back to third century B.C. There is evidence that ancient Egyptians used Windmills for grinding grain and pumping water from the Nile River for irrigation purposes [3]. Nowadays, Egypt is a developing country, with a population of about 80 million inhabitants. There is a growing awareness for renewable energy resources in south Egypt as a result of the aim of Egyptian government for rapidly increasing population and industrial development at this region. Furthermore, Egypt does not possess enough fossil fuel reserves at deep south country, possesses only in this area large resource for electricity generation hydropower (High Dam Aswan).

Also, Egypt has started to trade CO_2 Emission Certificates under the Kyoto Protocol. To reduce the CO_2 emissions and the high air pollution, the Egyptian government wants to use increasingly the available renewable energy sources [4]. Thus, to support this goal at Aswan region in south country, we introduce this research to encourage the construction of wind turbines at this area to produce “clean and renewable energy”.

The aim objective of this study is to present a technical assessment for wind power potential at Aswan region in Egypt and the possible applications for electricity generation with the cost analysis from the wind energy at this area.

2. Detailed analysis of surface wind distributions

In recent years a few attempts about Aswan region along the Nile River has been represented. Most early and important work in this area was directed towards that Aswan region have low pollution potential at afternoon all over the year and high pollution potential during early morning [5].

Aswan lies on latitude 23°57′ and longitude 32°49′ (see Fig. 1). Due to high elevation of this area, 193 m above ground level, winds over Aswan region generally high 6.9–7.5 m/s during the medium hub heights 50–70 m. Recently, one or a few years average cannot be representative of the real situation. Ten years is the minimum time where one can get a reasonable mean value in a given site [6].

Measurements of metrological data were carried out at Aswan City for a period ten years (1995–2004) by the Renewable Energy Authority in Cairo, Egypt. Where the Aswan mast is situated in the international airport of Aswan, about 2 km SW of the town of Sahara City. Lake Nasser is found to the east and south, at distances of about 3–5 km, and the High Dam Aswan is located about 5 km to the east of the site. There are several sheltering obstacles (airport buildings) close to the mast, in the NE, SE and SW directions. The airport area itself is also characterized by a higher roughness length than the surrounding sandy desert. The terrain is mostly flat or slightly undulating, expect to the NE where the Nile valley is located – about 5 km from the site.

The measured wind speed at a site is determined with height of anemometer 10 m above the ground level [7]. The wind velocity categorization on the basis of directions of 30 degrees are given in Table 1. Furthermore, this table indicates the mean monthly of wind speeds. The annual average wind speed for this site is 4.6 m/s.

Wind speed time series and air temperature observed for all months over the year are presented in Fig. 2. It is obvious from the comparison of these two time series that wind speed is more persistent with high scale in Summer season but in Winter period sudden changes due to the noticed decrease of the air temperature during the months from November to February throughout the year.

Table 1
Mean monthly wind speeds measured at 10 m hub height.

Sector	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
0	3.9	4.0	3.9	4.2	4.4	4.4	4.0	4.1	4.4	4.4	3.9	3.8
30	3.9	3.9	3.8	4.0	3.9	3.9	3.5	3.6	4.2	4.2	3.8	3.5
60	3.8	3.9	4.1	4.7	4.7	4.8	4.2	4.3	4.8	4.7	3.9	3.4
90	5.1	5.4	5.1	5.2	5.2	5.5	5.1	5.7	5.5	5.1	4.7	4.7
120	4.9	5.3	5.1	5.3	5.5	5.5	5.6	6.0	4.8	4.6	4.3	4.4
150	5.1	5.5	5.6	5.6	5.7	5.8	6.0	6.3	5.2	4.8	4.5	4.5
180	4.4	4.7	4.7	4.8	5.0	5.2	5.2	5.2	4.9	4.6	4.2	3.9
210	4.0	4.1	4.3	4.6	4.7	5.1	4.6	4.5	4.5	4.5	4.1	3.8
Mean	4.4	4.6	4.6	4.8	4.9	5.0	4.8	5.0	4.8	4.6	4.2	4.0

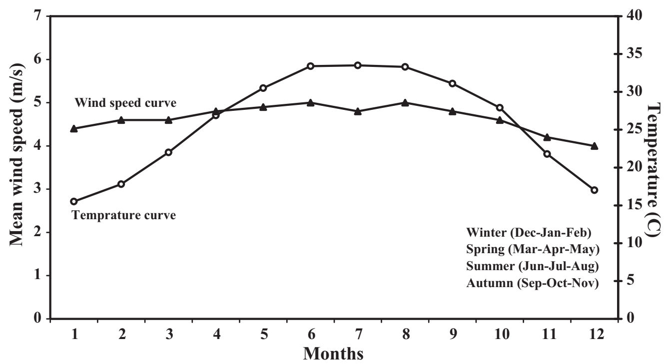

Fig. 2. Monthly variation of wind speeds and air temperature at 10 m height for Aswan station.

An integral view of Fig. 2 gives the following findings:

(1) Aswan's wind climate is characterized by the trade winds during Summer, where highest values measured of mean monthly wind speed occurred in Summer season. This can explained by the weather phenomena of land and sea breezes. Where Aswan region is specified by the broad Nile valley and Lake Nasser which is found to the east and south the station.
(2) From April to September, strong trade winds come from north. And from October to March wind direction suddenly changing accompanied by a drop in the average wind speed.
(3) The maximum value is recorded at Aswan station with 5.0 m/s during June and August. A minimum value of recorded temperature was 15.3 and 16.9 °C at January and December, respectively (Winter season).
(4) Annual average of air temperature at Aswan region throughout the year was 25.9 °C.
(5) Judging by the wind availability during the Winter season, one can eliminate the utilization of wind energy in space cooling applications in Egypt. This disadvantage can be overcome by storing the excess power generated by the Summer wind.

3. Sectoral wind speed frequencies

The effective utilization of wind energy entails having a detailed knowledge of the wind characteristics at the particular location. The distribution of wind speeds is important for the design of wind farms, power generators and agricultural applications like irrigation [8].

Table 2 describes the hourly percentage frequency measured at 10 m height, during the period of (1995–2004) for Aswan station. This table includes the sectoral frequencies and the wind direction. Analysis the data of Table 2 gives the following findings on the annual basis:

(1) The maximum frequency of occurrence is from north on the site, where 47.3% of hours have wind speed in the range 5.3 m/s.
(2) The frequencies from north northwest sector (330°) were 21.4% exceed 5.8 m/s.
(3) There were strong wind (6.1 m/s) blowing from west-northwest (300°) but their frequencies were quite low (10.6%).
(4) Other sectors frequencies were not higher than 10%.
(5) It is clear from this table that the wind remained between 5.3 and 6.1 m/s almost 79% of the time over the year. Since most modern wind turbines usually start producing energy above 3.5 m/s [9], the 79% availability of wind speed about the cut-in-speed of wind turbine is a very good indication of Aswan region being a potential site for wind farm development.

4. Wind rose

The wind rose provides information on the relative wind speeds in different wind directions. The wind roses were constructed using the measurements of wind speeds and corresponding wind directions. Like wind speed, wind roses also vary from one location to the other and are known as a form of meteorological fingerprint. Hence, a close look at the wind rose and understanding its message correctly is extremely important for sitting wind machines. So, if a large share of wind comes from a particular direction then the wind machines should be put against this direction [10].

Table 2
Sectoral wind speed frequencies with height of anemometer 10 m and Weibull parameters.

Sector	Frequency %	<1	2	3	4	5	6	7	8	9	11	13	15	17	>17	*c*	*k*
0	47.3	6	33	126	211	191	187	142	59	29	13	3	0	0	0	5.3	2.70
30	9.9	12	62	204	236	182	156	111	26	9	2	0	0	0	0	4.6	2.49
60	1.2	70	145	263	228	137	95	30	13	11	8	0	0	0	0	3.7	1.94
90	0.9	37	158	245	245	150	86	38	21	7	14	0	0	0	0	3.9	1.90
120	1.1	51	174	253	154	147	125	68	9	16	4	0	0	0	0	3.9	1.95
150	1.5	19	67	179	178	160	169	154	44	23	6	0	0	0	0	5.0	2.65
180	1.2	29	111	242	209	186	104	67	28	11	12	0	0	0	0	4.2	2.09
210	1.0	36	103	249	207	193	85	75	24	13	10	6	0	0	0	4.2	1.97
240	1.1	42	103	212	141	160	148	98	50	33	13	0	0	0	0	4.8	2.20
270	2.8	20	71	120	153	161	137	156	76	60	41	4	1	0	0	5.7	2.39
300	10.6	12	41	80	141	151	209	177	88	53	37	8	1	1	1	6.1	2.76
330	21.4	9	40	99	165	171	196	175	77	39	23	5	1	0	0	5.8	2.85
Total	100.0	11	46	132	193	179	181	145	60	32	17	3	1	0	0	5.4	2.61

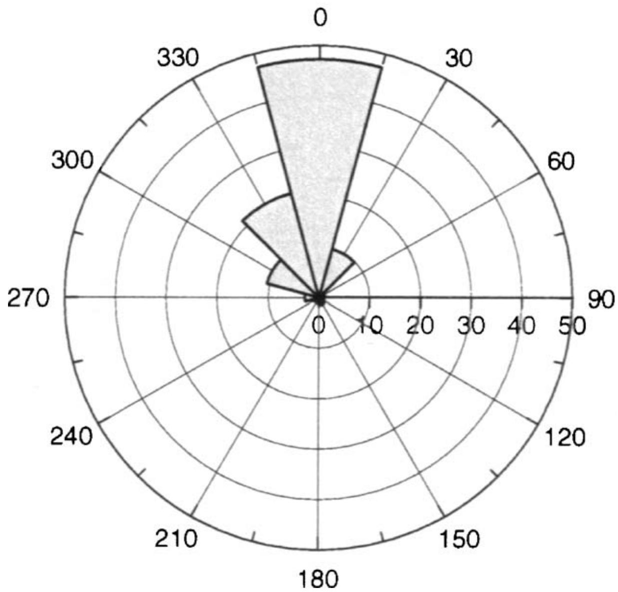

Fig. 3. Aswan wind rose during the year.

Fig. 3 shows the Aswan wind rose obtained from the analysis of measured data. An integral view of Fig. 3 leads to the following:

(1) The main wind directions are distributed over the sectors N, NNW and WNW. This may due to the local wind effects (see breeze and land breeze).
(2) The dominant prevailing wind direction for the Aswan Meteorological station is northly (360°).
(3) In this region, northern winds are effective. After northern winds, north-northwest are most effective.
(4) The effect of the wind that is observed at lowest degree is in the direction of 270°.
(5) The annual direction of wind speeds of different magnitudes is a valuable piece information in determining the potentialities [11]. Thus, north appears the only direction to consider in wind farm project at Aswan region.

5. Calculation methodology

It is well known that most wind speed data in the moderate-high wind speed range can be represented by the Weibull distribution [12], for which;

$$F(v) = 1 - \exp\left[-\left(\frac{V}{c}\right)^k\right] \tag{1}$$

where $F(v)$ is the probability that the mean wind speed is less than v, c a reference wind speed (scale parameter), and k a shape factor.

Eq. (1) can be manipulated to give:

$$\ln V = \ln c + \left(\frac{1}{k}\right)\ln[-\ln(1-F(V))] \tag{2}$$

Parameter estimation can then be readily undertaken by plotting $\ln V$ against $\ln[-\ln(1-F(V))]$, from which the slope is $(1/k)$ and intercept $\ln c$. This technique is generally based upon standard meteorological data, which is presented as the frequency with which the wind speed falls within discrete, usually of width at least 2 knot [13].

Also, earlier studies (Justus et al. [14]) have determined that a general trend exists between Weibull k values (or variance of the wind distribution) and the mean wind speed. Mathematically results can be expressed for average, high (90 percentile), and low (10 percentile) variability sites by:

$$k = \left|\begin{array}{l} 1.05\,V_m^{0.5}\,(\text{low}) \\ 0.94\,V_m^{0.5}\,(\text{average}) \\ 0.83\,V_m^{0.5}\,(\text{high}) \end{array}\right. \tag{3}$$

Recently, the following are recommended for the applications:

$$k = 0.83\,V_m^{0.5} \quad \text{for } V_m > 4\,\text{m/s} \tag{4}$$

Then, the mean wind speed V_m is related to k and c as follow:

$$V_m = c\Gamma(1 + k^{-1}) \tag{5}$$

The two parameters c and k can be used in estimating monthly or annual wind power density per unit area using the expression:

$$P_M = \frac{1}{2}\rho c^3 \Gamma\left(1 + \left(\frac{3}{k}\right)\right) \tag{6}$$

Eq. (6) shows that P_M; is a function of the cube of the wind speed. At this point an important aspect must be examined. Using the annual or monthly mean wind speed value, V_m, whether actual or derived from a Weibull fit, will not yield the right picture as far as P_M is concerned. The wind varies over time, hence wind speeds are distributed over the low and high wind speed ranges. This illustrates that the average of the cube of many different wind speeds will be much greater than the cube of the average speed.

Hence one must introduce another parameter known as the energy pattern factor (E.P.F), which adjusts the mean power density in Eq. (6) by introducing a correcting factor. This factor is known as the energy pattern factor, K_E.

The E.P.F., K_E may be deduced from the following [15,16]:

$$\begin{aligned} K_E &= \frac{\text{Total amount of power available in the wind}}{\text{Power calculated by cubing mean wind speed}} \\ K_E &= \frac{\text{Mean power density for the month}}{\text{Mean power density at the monthly mean speed}} \\ K_E &= \frac{\Gamma(1+(3/k))}{\Gamma^3(1+(1/k))} \end{aligned} \tag{7}$$

Hence, a more realistic value for the available power density at 10 m above the ground level is:

$$P_{M10} = \frac{1}{2}\rho K_E V_m^3 \quad (\text{W/m}^2) \tag{8}$$

where, ρ is the corrected annual mean air density for Aswan City = 1.179 kg/m^3 [which are taken from the results at Ref. [17]].

In addition, for a height less than 100 m, the power density of the wind above the ground level is given by [18,19]:

$$P_H = P_{M10}\left(\frac{H}{10}\right)^{3\alpha} \tag{9}$$

For the Egyptian terrain a roughness factor α = 0.25 can be used [20].

So, from Eqs. (8) and (9) the monthly wind energy available at any desired height (H) in meter, can be evaluated by the following new equation:

$$E_{H\,\text{monthly}} = 0.36\,\rho\, K_E\, V_m^3\left(\frac{H}{10}\right)^{3\alpha} \quad (\text{kW h/m}^2\ \text{month}) \tag{10}$$

6. Results and discussions

6.1. Weibull parameters and mean wind speed values

Two simple methods are available for fitting Weibull distributions to data. The data for monthly percentage frequency of wind speeds at Aswan region, which was obtained from the Egyptian Meteorological Authority, Egypt [21].

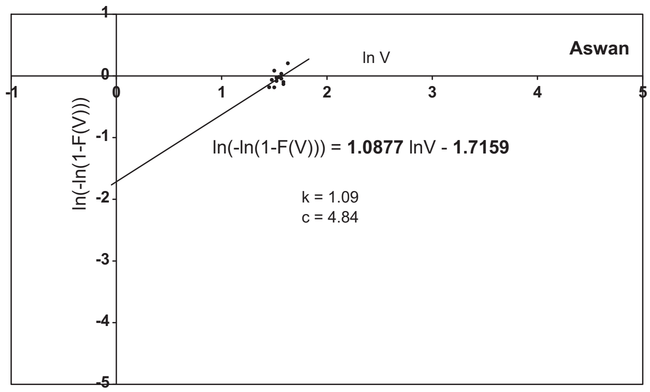

Fig. 4. Monthly observed values of ln $[-\ln(1-F(V))]$ plotted against $\ln V$ for Aswan station, through which the Weibull parameters are estimated.

In the linear regression method as mentioned above, Eq. (2), values of $\ln[-\ln(1-F(V))]$, where $F(V)$ is the cumulative distribution obtained by integrating $f(V)$, are plotted versus $\ln V$, and a straight line is fitted to the points. The slope of the line is k, and the intercept on the $\ln[-\ln(1-F(V))]$ axis is $-k\ln c$ giving c. From Fig. 4 the annual values of k and c are deduced.

i.e.

$$k = 1.09 \quad \text{and} \quad c = 4.84\,\text{m/s}.$$

Alternatively, using the method moments, applying Eqs. (4) and (5) with the mean monthly wind speed values to obtain the monthly values of k and c. The results are shown in Table 3.

On the other side, from Table 3 and Fig. 4 we can drive the following:

(1) It is clear from the results that both methods give identical estimates of the parameters k and c.
(2) The monthly values of k and c vary over a narrow range, where estimation of k and c depends mainly on the measured values of mean monthly wind speed (see Eqs. (4) and (5)). This confirms the stability of atmosphere throughout the year over Aswan region.
(3) In general, values of scale parameter are low during Winter months and high throughout Summer and Autumn seasons.
(4) The range of k is between 1.66 and 1.86 (at a height of 10 m). These small values during the year indicate widely dispersed data, i.e., the data tend to distributed uniformly over a relatively wide range wind of speed [22]. This has a positive implication on wind power generation at Aswan City because this means that the station experiences enough wind speed during the year to operate a wind turbine for a large part of time.

Table 3
Numerical values of Weibull parameters for monthly and annual wind speed distribution, at 10 m height.

Month	V_m	k	C (m/s)
Jan.	4.4	1.74	4.93
Feb.	4.6	1.78	5.17
Mar.	4.6	1.78	5.17
Apr.	4.8	1.82	5.40
May.	4.9	1.84	5.51
Jun.	5.0	1.86	5.63
Jul.	4.8	1.82	5.40
Aug.	5.0	1.86	5.63
Sep.	4.8	1.82	5.40
Oct.	4.6	1.78	5.17
Nov.	4.2	1.70	4.71
Dec.	4.0	1.66	4.48
Annual mean	4.6	1.79	5.22

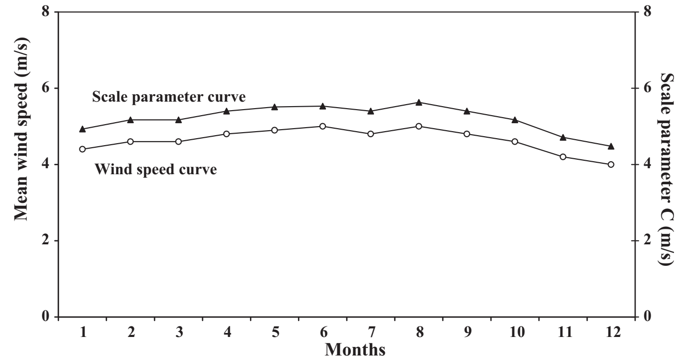

Fig. 5. Comparison of measured V_m and Weibull-calculated c wind speed values.

(5) Hence, the wind speed is sufficient during the whole year for high power generation using large wind turbine, a cut-in-speed of 4 m/s are recommended for Aswan station.

From the computation of mean wind speed for the 10 years, Fig. 5 has been prepared. Where Fig. 5 shows the estimated wind speed calculated assuming a Weibull distribution, c (m/s), as against the actual wind speed, V_m, values measured for the respective months over the aforementioned period. The important conclusion extracted from the figure is that:

(1) The differences between the points of the two curves were found to be insignificant.
(2) The similarity of both trends illustrates the good representation offered by such a model when compared to the actual measured data.
(3) And this a strong indication that: the wind potential in Aswan reign remained stable throughout the year. This information is in line with our previous results at Table 3 and Fig. 4.

6.2. Energy availability and energy pattern factor

Wolde-Ghiorgis [23] recommended that the two most important criteria that determine the potentiality of wind power in a given site are the mean yearly wind speed and the approximate air density. As mentioned before, calculation methodology section, the corrected annual mean air density for Aswan City was discussed and analyzed in our pervious research and the results was presented in Ref. [17].

For best performance, we focus on energy pattern factor, where the annual energy pattern factor (E.P.F.) that accounts for all variation in wind strength over the year is computed as the ratio between the energy available in the wind per year and the energy available at mean wind speed [24]. Until now, a key indicator to the size of an available wind resource is its annual average power density. Computation of this factor at a reference height of 10 m or 50 m allows for a general classification of the available resource and the subsequent estimation of its potential for wind energy applications [25].

By applying the measured wind data for Aswan station with Eqs. (7)–(10), the values of monthly energy pattern factor K_E, at a height of 10 m, and the monthly energy density available, E_{70}, at hub height 70 m over the year were calculated and listed in Table 4. The results of E_{70} lead to Fig. 6. From these table and figure, we notice that:

(1) There are a narrow change for the obtained monthly values of (E.P.F.), K_E, due to the shape parameter, k, is a steady between small range of values (1.66–1.86) (see Table 3).
(2) The seasonal average available of wind energy density is seen to vary between 497 and 688 kWh/m^2.

Table 4
Estimated monthly energy pattern factor K_E at 10 height and energy density available at 70 m height.

Month	K_E	E_{70} (kWh/m^2)
Jan.	1.044	163
Feb.	1.193	212
Mar.	1.193	212
Apr.	1.054	213
May.	1.054	227
Jun.	1.061	243
Jul.	1.054	202
Aug.	1.061	243
Sep.	1.054	213
Oct.	1.193	212
Nov.	1.044	141
Dec.	1.044	122
Annual mean	1.044	200

Table 5
Monthly estimated wind speed and wind power available at 100 m hub height and monthly plant load factor of wind turbine 1 MW assumed at Aswan station.

Month	V_{100} (m/s)	P_{100} (W/m^2)	PLF%
Jan.	7.8	295	19.7
Feb.	8.2	385	25.7
Mar.	8.2	385	25.7
Apr.	8.5	386	25.7
May.	8.7	411	27.4
Jun.	8.9	440	29.3
Jul.	8.5	367	24.5
Aug.	8.9	440	29.3
Sep.	8.5	386	25.7
Oct.	8.2	385	25.7
Nov.	7.5	256	17.1
Dec.	7.1	222	14.8
Mean	8.3	363	24.8

(3) The maximum extractable wind energy density also varies between 652 and 688 kWh/m^2 throughout Spring and Summer periods, respectively.
(4) The annual mean energy density available from the wind in this area at 70 m height was evaluated to be 200 kWh/m^2.
(5) Hence, the wind energy density during the half of the year (Spring–Summer seasons) at Aswan region is very high and suitable for large electricity generation.

6.3. Suitable wind turbine for Aswan region

Anyanwu and Iwuagwu [26] concluded that the available and maximum extractable wind power vary directly with the cube of the wind. This implies that an increase in wind speed of only 50% results in a wind power increase of above 200%. The wind data used in this study was measured at 10 m height above ground level. So, it is necessary to know the wind speed at wind turbine hub height. It is well known firstly that vertical extrapolation of wind speed in the first 100 m above the ground depends on:

- The characteristics of the surface (roughness), and
- The atmospheric stability.

From our results in last sections (Table 3), which confirms the stability of the atmosphere over Aswan region during the year. In addition, as mentioned in the beginning of the study, from the wind atlas analysis the measurements were taken in an open region (flat and homogenous area), so the roughness factor will taken as constant. Hence, we can find the wind at the hub height of the turbine. This is done using Hellman's exponential law [27–29]. The monthly wind speed values at 100 m hub height were calculated and the results are summarized in Table 5. This site has annual wind speed more than 8.3 m/s at 100 m height. Also, due to the common heights of modern and large wind turbines from 100 to 160 m above the ground level at the wind energy world market, the vertically extrapolated wind power values over the year of 100 m are estimated using Eqs. (8) and (9). The results are listed in Table 5.

To confirm the validity of our results in this section, the commercial wind turbine is chosen to suit the wind speed distribution at Aswan station, based on the data presented and the following discussion. Firstly, the frequency distribution of the wind speeds help towards answering questions of how long is a wind power plant out of action in the case of lack of wind, and how often does the wind power plant achieve its rated output [1]. As it was found (see Table 2 and Fig. 3), where the wind speed between 5.3 and 6.1 m/s almost 79% of the time over the year and the annual mean wind speed for Aswan station is 4.6 m/s at 10 m height, these speeds indicate economic feasibility for installing large wind machines for electricity generation. Since most modern wind turbines usually start producing energy above 3.5 m/s.

Secondly, we will use our method in previous article [30]. Where the plant load factor (PLF) was applied, that is used to determine the expected monthly and annual energy output of a Wind Energy Conversion System.

We obtain the monthly PLF at hub height 100 m for turbine 1 MW considered at Aswan station (see Table 5 and Fig. 7). And from both of them we can derive the following:

(1) The monthly values of PLF are greater than 25% throughout the year except at three months (January, November and December).
(2) The average annual PLF was obtained to be about 25% for the considered wind turbine with a capacity of 1000 kW.
(3) Where the real wind energies that could be produced by modern aero-generators are much less and vary between 25% and

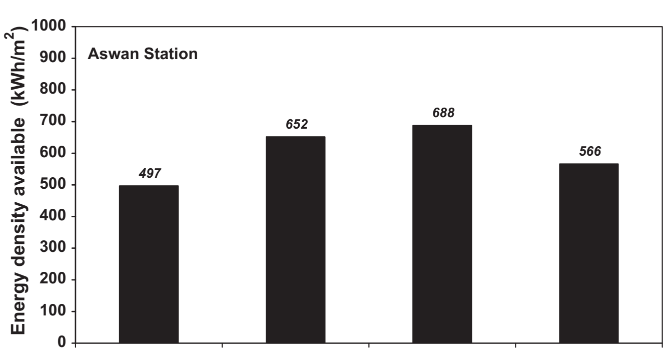

Fig. 6. Estimated seasonal wind energy density extractable at 70 m height over the year.

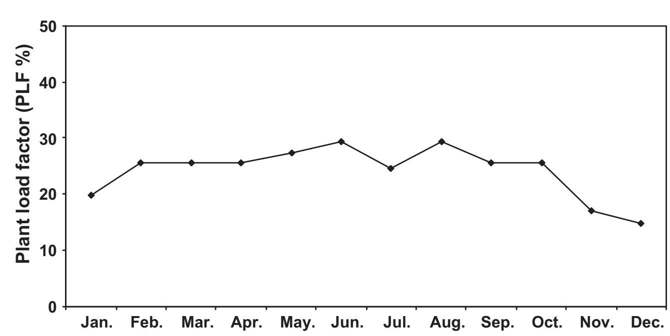

Fig. 7. Monthly plant load factor for assumed wind turbine of 1 MW with 100 m hub height at Aswan station.

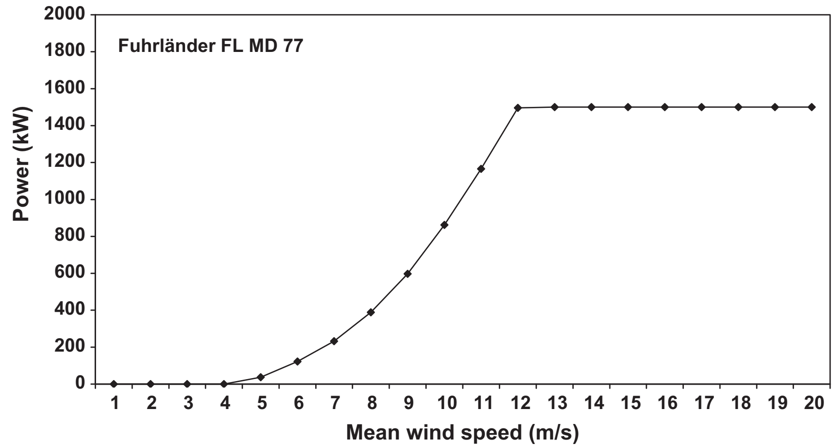

Fig. 8. The power curve for the chosen wind turbine [32].

48% [31]. Hence, we recommend that the used wind turbine at Aswan region must have rated power greater than 1 MW at 100 m height.

Finally, from the characteristics of the wind turbine (i.e., the rated power, cut-in speed, rated speed, and cut-out speed). So, the commercial wind turbine which has rated power 1500 kW and its cut-in speed = 4 m/s was selected. Fig. 8 shows the power curve (maximum power for optimum system) of (*Fuhrländer FLMD 77*) wind turbine, which has the lowest rated wind speed 12 m/s. That is very competitive compared to the actual wind turbines at the wind energy world market. Table 6 depicts the characteristic properties of the selected wind turbine with hub height 100 m.

6.4. Simulation of wind park and economic analysis

Aswan station was chosen to install 45 MW-wind farm consisting of 30 commercial wind turbines model (*Fuhrländer FLMD 77*), each of them having the power curve in Fig. 8 and its technical properties at Table 6. These turbines must locate 150 m distance apart each other to prevent energy production loses of park effect. Also the direction of the wind is of decisive significance for the evaluation of the possibilities of utilizing wind power. The direction statistics play an important role in the optimal positioning of a wind park in a given area [29]. Hence, at Aswan region, north appears the only wind direction to consider in wind farm project, which will be developed on the campus area.

In this section an estimate of the annual energy output of 45 MW-wind farm to operate at Aswan station together with an estimate the cost of kilowatt-hour are given. The primary goal of any financial analysis is to find out whether the benefits of an activity outweigh its costs. In the case of wind energy system the costs are relatively easy to determine once basic assumptions about money costs, escalation rates, etc. are made, but the benefits are not always easy to calculate. In our calculations we will mainly use the so called "present value" method to compare cost with benefits. It is a proper method to decide whether wind turbines are a sound investment within the basic assumptions about interest rates, etc.

So, the present value of money method is used to calculate the "present value cost" (PVC) of electricity produced per year, the following expression (Eq. (11)), given by Lysen [33] and referred by Türksoy [34], and Gökçek and Genç [35] is applied in the present study as well:

$$\mathrm{PVC} = I + C_{omr}\left[\frac{1+i}{r-i}\right] \times \left[1 - \left(\frac{1+i}{1+r}\right)^t\right] - S\left(\frac{1+i}{1+r}\right)^t \qquad (11)$$

In this equation, I is the investment cost of the wind machine, which includes the turbine price plus its 20% for the civil works and connection cables to the gird; C_{omr} is the operation maintenance and repair cost which is 25% of the annual cost of the turbine (machine price/life time); S is the scrap value (10% of the turbine price and civil work); t is the lifetime of the machine which is assumed to be 20 years.

In addition, in order to calculate PVC at two different cases in Aswan region, two different values for discount rate (r) and inflation rate (i) have been chosen to be:

$r_1 = 8\%$ and $i_1 = 6\%$
$r_2 = 15\%$ and $i_2 = 12\%$

After using wind data for Aswan station with WASP program. The annual energy gain from the wind farm containing of 30 machines with total capacity of 45 MW was found to be 152,566,800 kWh/year. And in case of the wind farm, the capital investment, I, is taken as the number of units multiplied by the unit price, from which PVC value was obtained [36]. The results are

Table 6
Annual energy gain at Aswan station and technical characteristics of wind turbine *Fuhrländer FLMD 77*.

Turbine model	*Fuhrländer FLMD 77*
E_{out} (kW/h/year)	5,085,560.0
Rated power (P_r)	1500 kW
Hub height	100 m
Rotor diameter	77 m
Swept area	4657 m^2
Number of blades	3
Cut-in wind speed (V_{ci})	4 m/s
Rated wind speed (V_r)	12 m/s
Cut-off wind speed (V_{co})	20 m/s
Price/Euro	1,700,000

Table 7
Expected annual energy production and the costs for the 45-MW wind farm at Aswan station.

Parameter	Case I	Case II
E_{out} (kWh/m^2)	152,566,800	152,566,800
C_f	39%	39%
i	6%	12%
r	8%	15%
PVC	67,527,740	67,365,415
Cost (€ cent/kWh)	2.213	2.207

depicted in Table 7. Where the cost electricity per kWh at Aswan station is obtained by dividing the PVC by the total kWh at the station.

As mentioned at other works [37–40], the capacity factor is still an important indicator of wind turbine performance evaluation. This factor is given as the ratio of the actual annual energy output to the theoretical maximum output, if the machine were running at its rated power during all the 8760 h of the year. From Table 7 we draw the following:

(1) The obtained capacity factor 39% per year is a very good indicator for the wind farm project at Aswan station.
(2) The cost of energy results reported at two different values of (r) and rate (i) are similarly. So, the expected electricity generation has not mainly affected by the increase in discount rate (r) and inflation rate (i).
(3) Hence, the cost of electricity from wind energy depends greatly on the annual mean wind speed at the site.
(4) The generation cost is about 2€ cent/kWh from 45 MW-wind farm assumed to be installed at Aswan City, which is considered as economically valuable price compared to the national tariff system.

7. Conclusions and recommendations

As seen from the results of the present analysis, the research has lead to the following:

(1) Aswan station along the Nile River in Egypt has a huge wind potential enough to produce electricity and its wind blows at speed 5.3 and 6.1 m/s for 79% of the time over the year at 10 m hub height.
(2) It is worth-while to remark that throughout the years (1995–2004) the prevailing winds are north (360°) on a percentage 47.3%. Thus, north appears the only direction to consider in wind park project at Aswan station.
(3) Based on the obtained values of Weibull parameters the atmosphere is stable during the year over Aswan region and the wind speed is sufficient throughout the whole year for high power generation using large wind machines with a cut-in-speed of 4 m/s are recommended.
(4) The annual mean energy density available from the wind at this area was evaluated to be 200 kWh/m^2 at 70 m height. Also, the extractable wind energy density over the *half* of the year (*spring and summer seasons*) is very high and suitable for electricity generation largely.
(5) We concluded that the used wind turbine at Aswan region must have rated power greater than 1 MW at 100 m height. So, for this area the commercial wind turbine (*Fuhrländer FLMD 77*) with a capacity of 1.5 MW was chosen.
(6) With the purpose of reducing the use of conventional power plants and the environmental problems associated with them. It can recommend that a 30 wind turbines of *Fuhrländer FLMD 77* arranged in a wind farm of 45 MW total power can be established on Aswan station. The actual yearly energy gain from these wind farm was 152,566 MWh/year and the obtained capacity factor is high 39%.
(7) Additionally, electricity generated after using 45 MW total power wind farm at Aswan City is economically feasible at a cost of 2€ cent/kWh. This obtained specific price is locally valuable compared to the national tariff system.

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